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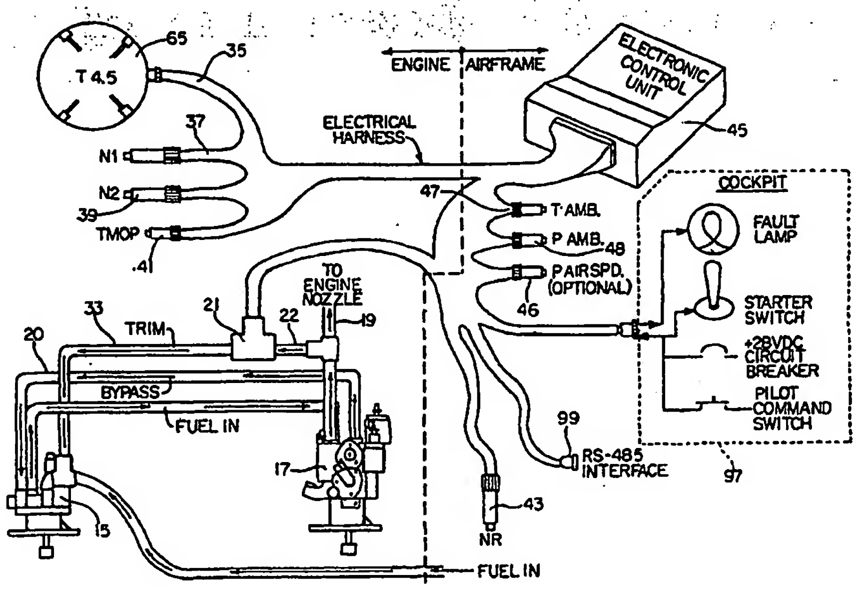

(57) Abstract

A fuel flow control system for turbine engine compries a hot-start overtemperature avoidance system. The fuel line to the engine nozzle includes a pump (15) having a pressure regulation bypass and additionally, a trim line (33) connecting the main fuel control (17) to the inlet of pump (15). The main fuel control (17) delivers fuel to the nozzle via line (19). A solenoid valve (21) is used to reduce the fuel flow at start-up depending on the engine speed detectors (37, 39, 43) and the exhaust gas sensors (35).

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TURBINE ENGINE CONTROL SYSTEM, AIRCRAFT ENGINE FUEL DELIVERY SYSTEM

Priority is claimed upon U.S. provisional patent application 60/111,858 filed December 11, 1998.

The present invention relates generally to fuel delivery systems for engines, especially gas turbine engines, and more particularly to such fuel delivery systems for aircraft such as helicopters and small fixed-wing turboprops incorporating engine temperature limiting features during engine start. The system reduces the pilot workload by automatically controlling the engine temperature during engine starts.

BACKGROUND OF THE INVENTION

Many present control systems for turbine engines do not provide temperature limiting during engine start. Subsequently, under certain ambient conditions, battery conditions, manual control adjustments etc., the engine can overheat ("overtemp") thus causing delay or cancellation of the flight or unscheduled engine maintenance. In addition, the pilot has full responsibility to cut off the fuel when a potential hot start may occur. For example, a low battery condition when attempting to start a gas turbine engine results in a slower than normal engine cranking speed; however, fuel is supplied at the normal rate resulting in an over-rich fuel/air mixture and increased engine heating during the start-up process. If a hot start occurs, the engine shut off and restart attempted, the battery may be in an even more depleted condition aggravating the problem.

An audible alarm indicative of over-stress limits including temperature, output torque and engine speed, instructing the pilot to provide the corrective action is shown in U.S. Patent 4,619,110. Water and/or additional fuel may also be automatically injected or the engine fuel flow automatically reduced.

A proposed solution to automatically avoiding hot start problems is provided in U.S. Patent No. 3,902,315 where fuel flow during engine start is initially controlled by an intentionally over-rich scheduled function of engine speed only. The fuel flow control is switched to an acceleration and speed control schedule upon sensing, inter alia, an excessive tailpipe temperature which temperature is a function of both compressor inlet pressure and engine

speed.

Another U.S. Patent considering the hot start possibility is 4,350,008 where the fuel flow rate is reduced upon sensing an excessive turbine temperature and that reduced flow continued until the over-temperature condition is corrected.

U.S. Patent 5,101,619 teaches a hot start correcting system where fuel flow to the engine is completely shut-off for a specific brief period of time when an overtemperature condition is sensed. Fuel flow is then resumed for a longer specific time period regardless of the sensed temperature.

All four of these patented schemes utilize one fuel control valve for all fuel flow control.

The hot start problem has also been addressed in U.S. Patent 3,964,253 where an additional parallel fuel flow path provides enhanced fuel richness during start with that additional flow being shut-off in the event an excessive temperature is sensed.

None of these patented schemes continues to monitor temperature and tailor the reduced fuel flow to the monitored temperature.

SUMMRY OF THE INVENTION

It is desirable to provide automatic temperature limiting during engine start and to provide such temperature limiting in a continuous, economical, relatively simple and retrofitable way. An externally mounted fuel solenoid valve provides an inexpensive solution eliminating the need for additional calibration or recalibration of the main fuel control. Only external plumbing is required for field installation.

The present invention provides solutions to the above problems by providing a fuel burning engine overtemperature avoidance system which monitors an engine temperature indicative temperature such as exhaust gas temperature, and diminishes fuel flow to the engine, for example, by diverting a portion of the fuel flow to the engine from the main fuel control back to the engine fuel pump, when the monitored temperature exceeds a threshold. A pulse width modulated control signal to a solenoid operable valve cyclically

enables and disables the return flow of a portion of the fuel flow to the engine from the main fuel control back to the engine fuel pump. The period of cyclic enabling and disabling is fixed and the fraction of each cycle during which enabling occurs is controlled in accordance with the monitored exhaust gas temperature. Undiminished fuel flow is resumed when the monitored temperature falls below the threshold temperature. An engine operating parameter such as gas generator speed, is also monitored and fuel flow diminution to the engine is prevented despite the monitored temperature exceeding the threshold temperature when the monitored parameter exceeds a predetermined level such as engine idle speed. The threshold temperature may be determined by measuring ambient temperature and computing the threshold as a prescribed increment above the measured ambient temperature. Recording monitored temperature, gas generator speed and fuel flow diminution, allows subsequent modification of the engine fuel system to provide enhanced engine performance achieving overtemperature avoidance with reduced fuel flow diminution.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a schematic illustration of an engine control system according to the present invention;

Figure 2 is a more detailed schematic illustration of the fuel flow portion of the system of Figure 1;

Figure 3 is a simplified block diagram illustrating control of the solenoid valve of Figure 2;

Figure 4 is a block diagram of the temperature limiting portion of the electronic control of Figure 1; and

Figure 5 graphically illustrates temperature control achieved by the system of Figures 1-4 during start up.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawing.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In Figure 2, a simplified helicopter or fixed-wing aircraft free power

turbine engine 49 is illustrated. The engine has a power output shaft 63 which is conventionally coupled to the helicopter rotor or aircraft propeller (not shown). Shaft 63 is driven by a power turbine 59. Air enters the engine housing 51 by way of compressor 53 and forms a combustible fuel/air mixture in combustor 61. The exiting combustion gasses power the compressor turbine 57 which drives shaft 55 and the compressor 53 and also drive the power turbine 59. Exhaust gasses exit by way of chamber 65 and the temperature (T4.5) of the exiting gasses is monitored by a set of temperature probes within chamber 65.

Referring now to Figures 1 and 2, in fuel system 10 fuel is supplied from a tank 11 and a remotely located pump 13 to the engine fuel pump 15, and then, by way of the main fuel control 17 and conduit 19, to the nozzles within combustor 61 of turbojet engine 49. In addition to a conventional head maintenance bypass 20 for maintaining a relatively constant pressure differential across the fuel control valve 17, a fuel trim solenoid or bypass 21 is controllable to divert fuel from the engine by way of lines 22 and 33 back to the inlet of pump 15. A torque motor or electrical valve could be used instead of a solenoid. This second fuel bypass operates independently from the first bypass 20 under certain conditions to divert fuel exiting the fuel control 17 away from the engine and back to the fuel pump 15 to maintain an engine temperature below a threshold level. Bypass 21 is operable only during engine start-up, and is enabled upon engine light-off and disabled when the engine reaches normal idle speed.

The bypass 21 includes a solenoid operable valve 29, which may be either a ball type or balanced poppet type, and a check valve 23, and an orifice or flow restrictor 27, in series. Fuel trim solenoid valve assembly 21 is set or calibrated to flow 13.5-17.0 pph (Jet A Fuel) at 100 psid. Passing the diverted fuel flow through this flow limiting orifice 27 serves to limit the quantity of fuel diverted. Because of the small orifice, 75 micron screens 25 and 31 are also installed (on either side) to remove particulate matter and prevent debris blockage. The check valve 23 is at the outlet of the solenoid

valve 29 so that when fuel pressure increases (due to heating) between the solenoid valve 29 and check valve 23 and the solenoid valve 29 is closed, the check valve 23 will open and allow the heated fuel to return to the pump 15.

The solenoid valve 29 of the fuel trim solenoid 21 is controlled by pulse width modulated signals from the electronic control unit or ECU 45 which may be of either a digital or analog architecture. This Control unit 45 receives input information from a torque meter oil pressure sensor or TMOP 41, the gas generator (shaft 55) speed N1 on electrical harness line 37, power turbine (shaft 63) speed N2 from speed sensor 39, rotor speed NR from speed sensor 43, T4.5 turbine outlet temperature by way of line 35, ambient pressure (PA) from sensor 48, ambient temperature (TA) from sensor 47, and airspeed from sensor 46.

The system 10 reduces fuel flow to the engine nozzles (derichment) by pulse-width modulation (PWM) of the fuel trim solenoid 21. Control of the solenoid valve 29 is accomplished using the electronic control unit 45. The duty cycle of the solenoid valve 29 is dependent upon the sensed T4.5 temperature in relation to the temperature limit set in the ECU 45. The system derichment is locked out when the engine speed is above ground idle (60% of rated speed). The fuel derichment algorithms installed in the ECU are based primarily on gas generator shaft speed N1, exhaust gas temperature T4.5, and are biased by ambient or inlet air temperature TA. Figure 3 illustrates a simple algorithm wherein if the gas generator speed N1 exceeds 60% of the full throttle speed NF (a "yes" from block 50), the solenoid 21 is disabled as indicated at 67. Disabling typically occurs 20 to 30 seconds after light off depending upon the engine model. The system may also monitor rotor speed and disable the solenoid 21 if the aircraft is airborne as indicated, for example, when NR exceeds 60% of rated rotor speed. Outlet temperature T4.5 is compared to some predetermined maximum value Tmax at 69 and, if that maximum is exceeded, the solenoid 21 duty cycle is increased, that is, the portion of each cycle during which the solenoid is enabled is increased,

as shown at 73. Tmax is typically some maximum permissible increment above ambient temperature TA. Otherwise, that duty cycle is decreased as at 71. The T4.5 temperature limits set in the system are those specified in the applicable engine manual.

Figure 4 illustrates the logic controlling the generation at 95 of the pulse width modulated signals controlling solenoid 21. Table 87 contains a predicted fuel flow schedule for the particular engine as a function of gas generator speed N1. The values which may be read from the light-off table 77 are functions of both the gas generator speed as indicated on line 37 and ambient temperature as indicated on line 47. The TA input provides the capacity for the fuel mixture to be enriched at lower temperatures. The light-off table 77 is utilized only if the detector logic 75 fails to detect a light-off indicative temperature on line 35. Otherwise, switch 81 couples the ramp-out logic 79 to one input of the select high circuit 83. A start Table 85 contains a fuel flow schedule as a function of both gas generator speed and ambient temperature and, during start-up, the higher of the two values which is indicative of the desired open-loop flow, is supplied from circuit 83 to the summer 91. The other summer input is from the schedule table 87. The output of summer 91 provides one input to the summer 93 while the other is provided by the temperature limiting PID loop 89 which provides a flow cutback signal indicative of the sensed temperature T4.5. The resultant deriching signal controls the pulse width modulation signals emanating from generator 95. Figure 5 is illustrative of the operation of the circuit of Figure 4.

In Figure 5, the abscissa samples times begin at light off as detected at 75. At about sample number 100, circuit 89 indicates fuel cut back is called for and fuel trim solenoid 21 is enabled. The sensed temperature drops somewhat and at about sample number 107 the solenoid is shut off. Again the temperature rises. The monitoring and reduction of fuel is repeated so long as the monitored parameter (N1) remains below the predetermined 60% threshold. Energization of the solenoid approximately corresponds to the relative maxima of the temperature curve between sample number 100 and

sample number 300. Thereafter, the control is quiescent until the gas generator speed reaches the 60% level at which time operation of the solenoid is discontinued.

Returning to Figure 1, the other inputs read by the ECU are used for backup control should the primary inputs fail. Other features for the system include exceedence monitoring (all inputs) and potentially automated power checks. Inputs and outputs between the pilot and the system are indicated generally at 97 and include a fault lamp which acknowledges failure of the system, a circuit breaker which produces pilot override for catastrophic system failure, a pilot command switch input for pilot request for system status and power check. A serial data bus 99 is also provided for maintenance actions (data download) and set-up via a remote personal computer. This allows the recording of monitored temperature, gas generator speed and fuel flow diminution, and subsequently modifying the engine fuel system to provide enhanced engine performance achieving overtemperature avoidance with reduced fuel flow diminution.

WHAT IS CLAIMED IS:

1. An overtemperature avoidance process for a fuel burning engine, comprising the steps of:

monitoring a temperature indicative of engine temperature;

diminishing fuel flow to the engine (49) when the monitored temperature exceeds a threshold temperature;

monitoring an engine (49) operating parameter; and

precluding fuel flow diminution to the engine (49) despite the monitored temperature exceeding the threshold temperature when the monitored parameter exceeds a predetermined level.

2. The process of Claim 1, wherein the monitored temperature is exhaust gas temperature.

3. The process of Claim 1, wherein the engine (49) is a turbojet engine (49) with a free power turbine (59) and the monitored parameter is gas generator speed.

4. The process of Claim 1, including the steps of measuring ambient temperature and computing the threshold temperature as a prescribed temperature increment above the measured ambient temperature.

5. The process of Claim 1, wherein the engine (49) is a turbojet engine (49) with a free power turbine (59) , the monitored parameter is gas generator speed and the monitored temperature is exhaust gas temperature, the process further including for an engine fuel system (10) the additional steps of recording monitored temperature, gas generator speed and fuel flow diminution, and subsequently modifying engine fuel system (10) operation to provide enhanced engine (49) performance by achieving overtemperature avoidance through reduced fuel flow diminution.

6. The process of Claim 1, wherein the monitored parameter is engine speed and the predetermined level is engine idle speed.

7. The process of Claim 1, wherein fuel normally flows from an engine fuel pump (15) through a main fuel control (17) to the engine (49), the step of diminishing fuel flow to the engine (49) including diverting a portion of the fuel

flow from the main fuel control (17) back to the engine fuel pump (15).

8. The process of Claim 7, further including the step of passing the diverted fuel flow through a flow limiting orifice (27) to limit the quantity of fuel diverted.

9. The process of Claim 1, further including the step of resuming undiminished fuel flow when the monitored temperature falls below the threshold temperature.

10. The process of Claim 9, further including the step of continuing the monitoring, diminishing and precluding steps after the step of resuming so long as the monitored parameter remains below the threshold temperature.

11. The process of Claim 1, wherein fuel normally flows from an engine fuel pump (15) through a main fuel control (17) to the engine (49), the step of diminishing fuel flow to the engine (49) including cyclically enabling and disabling a return flow of a portion of the fuel flow from the main fuel control (17) back to the engine fuel pump (15).

12. The process of Claim 11, wherein the period of cyclic enabling and disabling is fixed and a fraction of each cycle during which enabling occurs is controlled in accordance with the monitored temperature.

13. An aircraft having an engine (49), an engine exhaust gas temperature sensor (35) and an engine fuel supply system including a fuel pump (15) and a fuel control (17) for controlling the flow of fuel from the pump (15) to the engine (49), the improvement comprising:

a controllable fuel flow bypass (20) for diverting selectively fuel exiting the fuel control (17) away from the engine (49) and back to the fuel pump (15) to thereby decrease the rate of fuel flow to the engine (49); and

means for enabling the fuel flow bypass (20) during engine (49) start-up and for disabling the fuel flow bypass (20) when the engine (49) reaches normal idle speed.

14. The improvement of Claim 13, wherein the fuel flow bypass (20) includes a solenoid operable valve (29), the improvement further comprising means responsive to sensed exhaust gas temperature for supplying a pulse

width modulated control signal (95) to the solenoid operable valve (29).

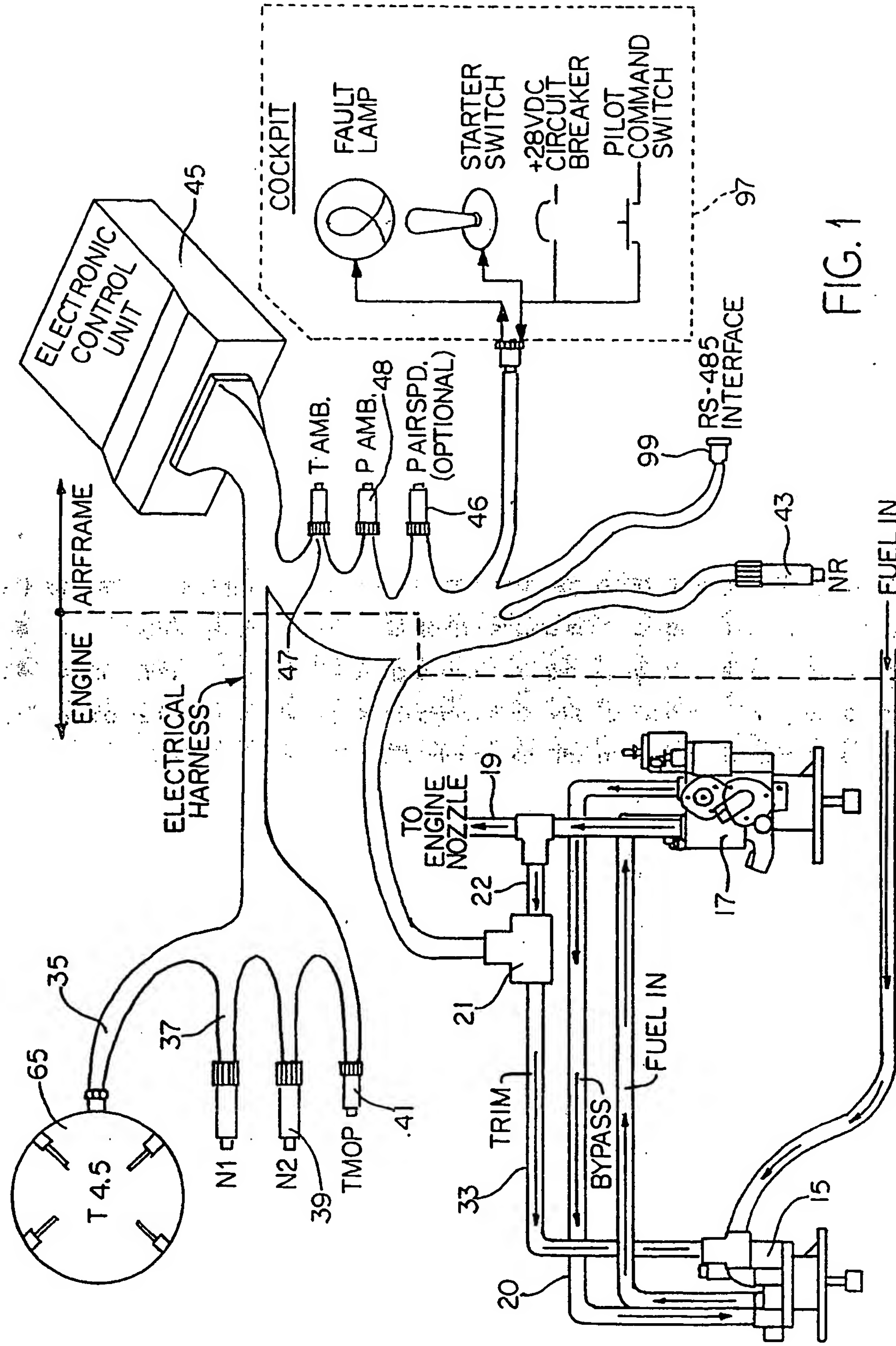
15. The improvement of Claim 13, wherein the fuel flow bypass (29) includes a particulate matter filter (25, 31), a flow limiting orifice (27), and a solenoid actuable valve (29) connected in series between the fuel control (17) and the fuel pump (15).

16. A fuel delivery system comprising a fuel control valve (17) for supplying metered fuel flow to an engine (49), a fuel pump (15) for supplying fuel from a fuel source (11) to the fuel control (17), a first fuel bypass (33) for diverting fuel exiting the fuel control (17) away from the engine (49) and back to the fuel pump (15) to maintain a relatively constant pressure differential across the fuel control (17) and a second fuel bypass (20) operable independently from the first fuel bypass (33) for diverting fuel exiting the control (17) away from the engine (49) and back to the fuel pump (15) to maintain an engine temperature below a threshold level.

17. The fuel delivery system of Claim 16, wherein the second fuel bypass (20) is operable only during engine (49) start-up, the system (10) further including means for enabling the second fuel bypass (20) upon engine light-off and disabling the second fuel bypass (20) when the engine (49) reaches normal idle speed.

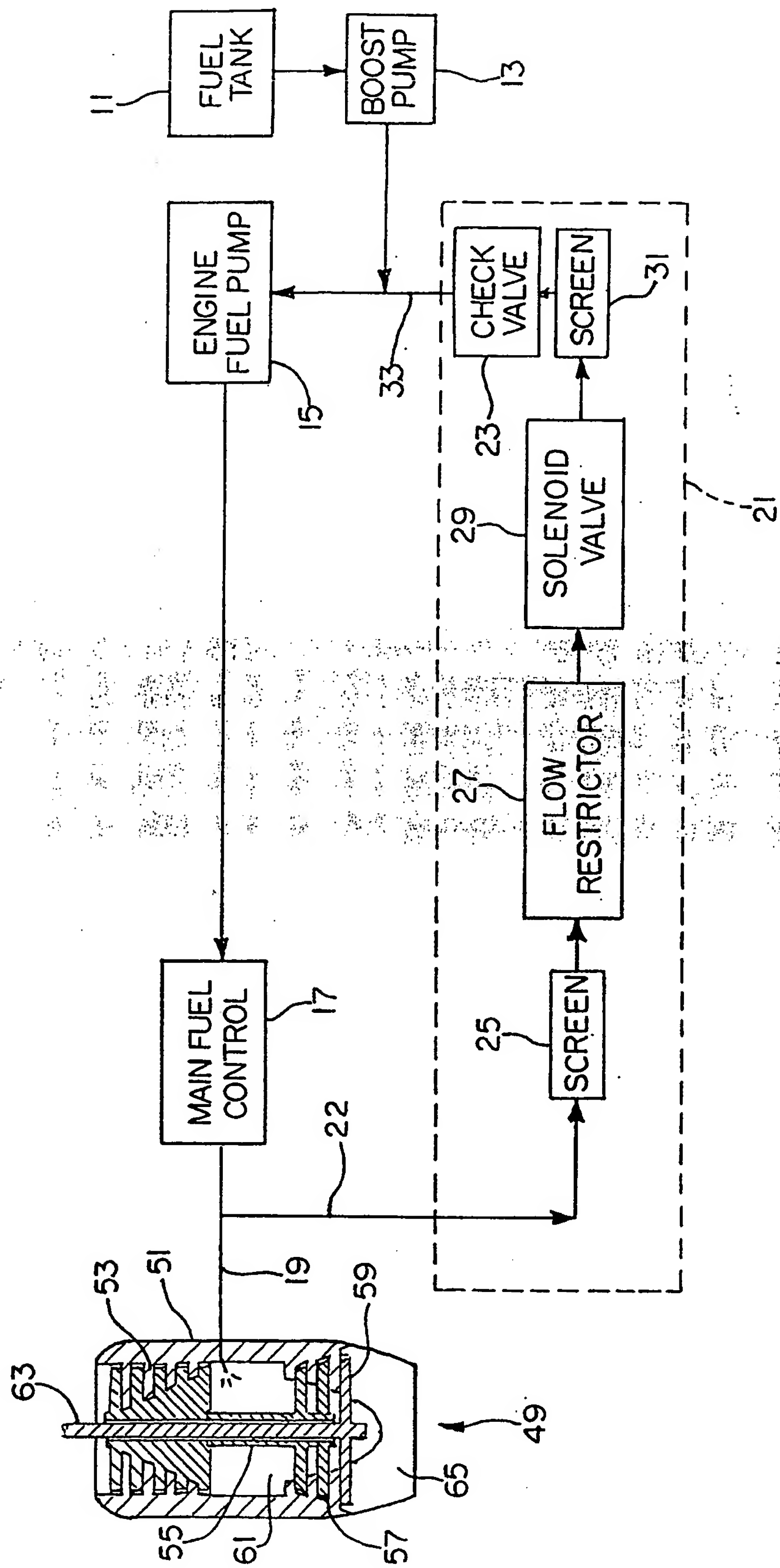
18. The fuel delivery system of Claim 16, wherein the second fuel bypass (20) includes a particulate matter filter (25, 31), a flow limiting orifice (27), a solenoid actuatable valve (29), and a check valve (23) connected in series between the fuel control (17) and the fuel pump (15).

19. The fuel delivery system of Claim 16, wherein system (10) includes an engine exhaust gas temperature sensor (35) and the second fuel bypass (20) includes a solenoid operable valve (29), and means responsive to sensed exhaust gas temperature for supplying a pulse width modulated control signal (95) to the solenoid operable valve (29).



ELECTRONIC CONTROL UNIT
45
COCKPIT
FAULT LAMP
STARTER SWITCH
+28VDC CIRCUIT BREAKER
PILOT COMMAND SWITCH
97
T AMB.
P AMB.
48
P AIRSPD. (OPTIONAL)
46
47
99
RS-485 INTERFACE
43
NR
FUEL IN
AIRFRAME
ENGINE
ELECTRICAL HARNESS
TO ENGINE NOZZLE
19
22
17
21
FUEL IN
BYPASS
TRIM
33
15
20
35
65
T 4.5
37
N1
N2
39
TMOP
41

FIG. 1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11
BOOST PUMP
13
ENGINE FUEL PUMP
15
33
CHECK VALVE
23
SCREEN
31
SOLENOID VALVE
29
21
FLOW RESTRICTOR
27
MAIN FUEL CONTROL
17
SCREEN
25
22
19
51
53
63
59
49
65
55
61
57

FIG. 2

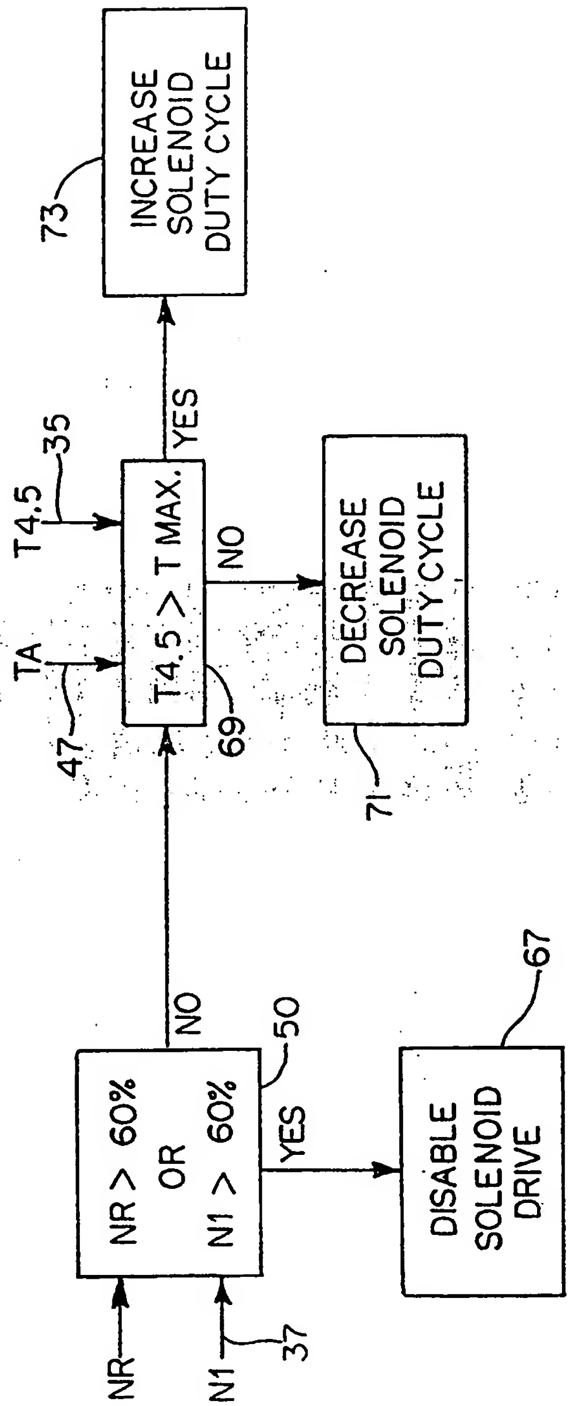
NR
N1
37
NR > 60% OR N1 > 60%
50
YES
DISABLE SOLENOID DRIVE
67
NO
TA
47
T4.5
35
T4.5 > T MAX.
69
NO
DECREASE SOLENOID DUTY CYCLE
71
YES
INCREASE SOLENOID DUTY CYCLE
73

FIG. 3

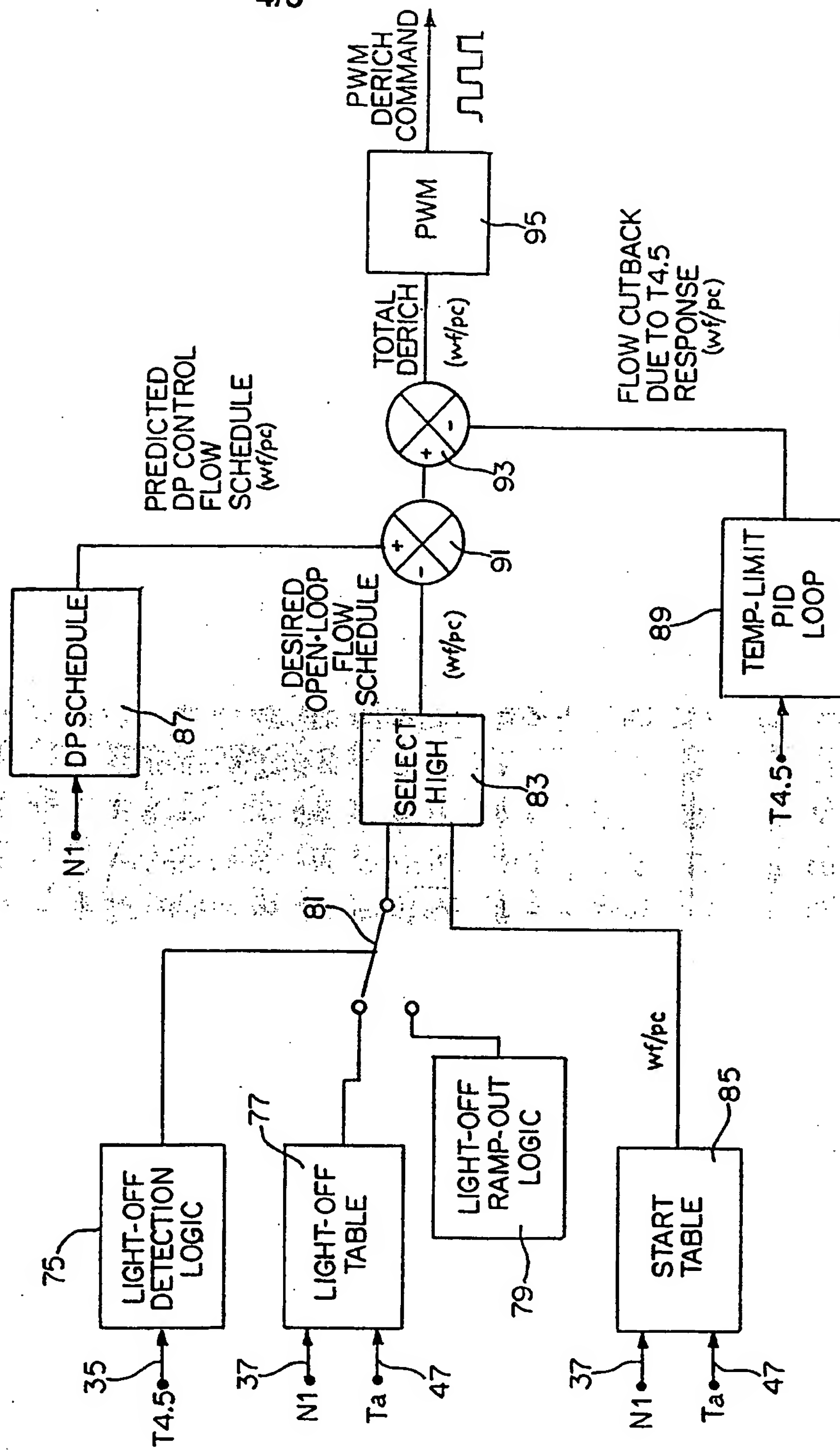
PWM
DERICH
COMMAND
PWM
95
TOTAL
DERICH
(wf/pc)
FLOW CUTBACK
DUE TO T4.5
RESPONSE
(wf/pc)
PREDICTED
DP CONTROL
FLOW
SCHEDULE
(wf/pc)
93
91
DP SCHEDULE
87
N1
DESIRED
OPEN-LOOP
FLOW
SCHEDULE
(wf/pc)
SELECT
HIGH
83
TEMP-LIMIT
PID
LOOP
89
T4.5
81
wf/pc
85
77
LIGHT-OFF
DETECTION
LOGIC
75
LIGHT-OFF
TABLE
LIGHT-OFF
RAMP-OUT
LOGIC
79
START
TABLE
35
T4.5
37
N1
Ta
47
37
N1
Ta
47

FIG. 4

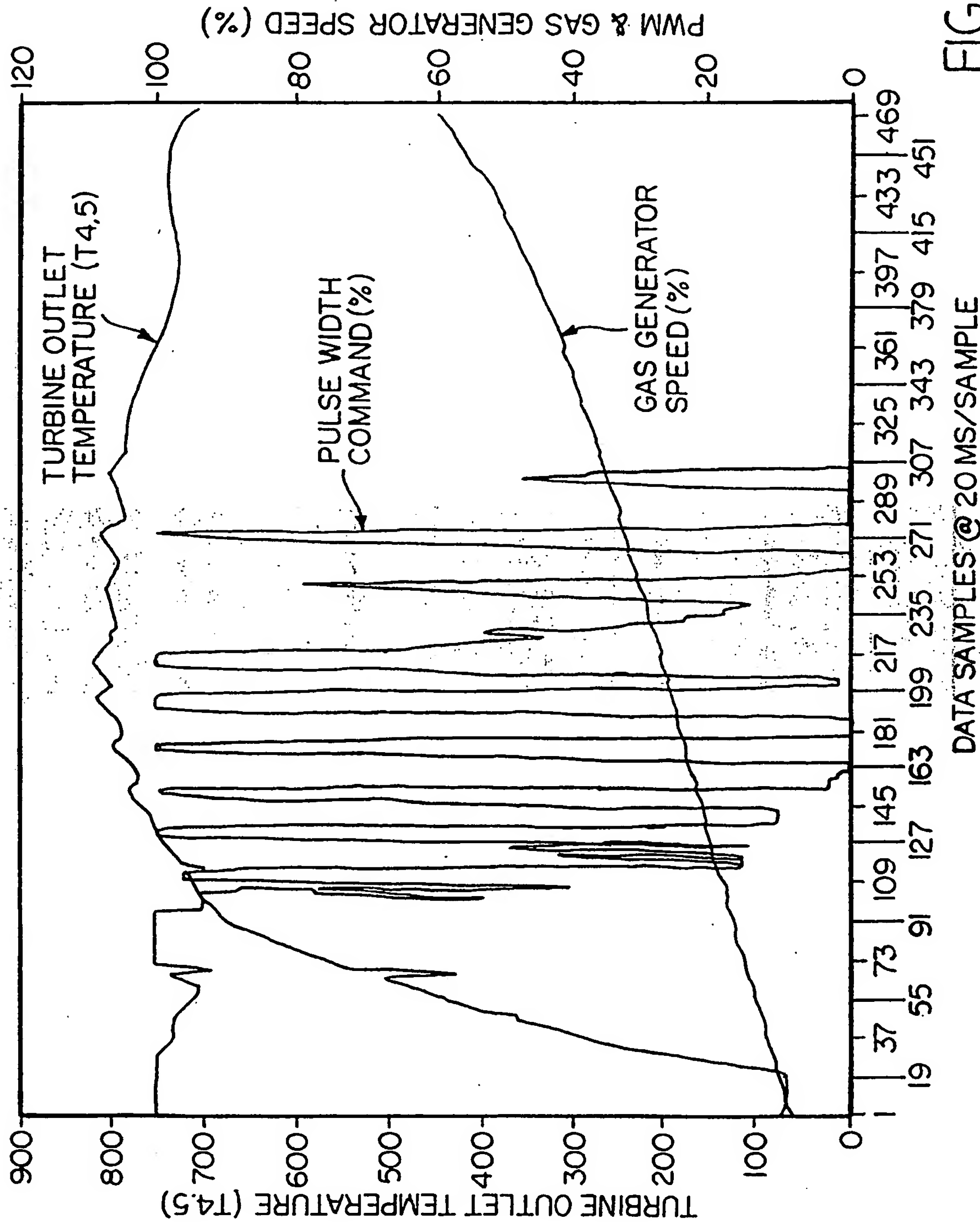
PWM & GAS GENERATOR SPEED (%)
120
100
80
60
40
20
0
TURBINE OUTLET TEMPERATURE (T4.5)
900
800
700
600
500
400
300
200
100
0
DATA SAMPLES @ 20 MS/SAMPLE
1
19
37
55
73
91
109
127
145
163
181
199
217
235
253
271
289
307
325
343
361
379
397
415
433
451
469
TURBINE OUTLET TEMPERATURE (T4,5)
PULSE WIDTH COMMAND (%)
GAS GENERATOR SPEED (%)

FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/28787

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F02C7/26 F02C9/28 F02C9/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F02C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5 165 223 A (VAVREK GARY P ET AL) 24 November 1992 (1992-11-24) column 4, line 30 -column 6, line 18; figure 3 column 2, paragraph 2	1-3,5,6, 9-12 1,7,8, 13,14, 16,19
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X	US 5 212 943 A (HARRIS JAMES J) 25 May 1993 (1993-05-25) column 5, line 45 -column 6, line 22; figure	1-3

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 April 2000	03/05/2000

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/28787

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 464 895 A (MORRISON TERRY ET AL) 14 August 1984 (1984-08-14) column 2, line 31 -column 3; figure	1-3
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1

INTERNATIONAL SEARCH REPORT

..formation on patent family members

Interr   nal Application No
PCT/US 99/28787

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